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(54) **EXHAUST GAS RECIRCULATION CONTROL SYSTEMS AND METHODS**

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F02D 41/30	(2006.01)
F02D 41/12	(2006.01)
F02D 41/40	(2006.01)
F02D 41/00	(2006.01)
F02D 41/26	(2006.01)

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CPC ***F02D 41/30*** (2013.01); ***F02D 41/005*** (2013.01); ***F02D 41/12*** (2013.01); ***F02D 41/402*** (2013.01); *F02D 41/0062* (2013.01); *F02D 41/266* (2013.01)

(58) **Field of Classification Search**

CPC F02D 41/30; F02D 41/12; F02D 41/005; F02D 41/402; F02D 41/266; F02D 41/0062

USPC 701/101–105, 108; 123/445, 299, 305, 123/568.21, 568.11, 568.14, 568.16, 672; 60/602, 605.2

See application file for complete search history.

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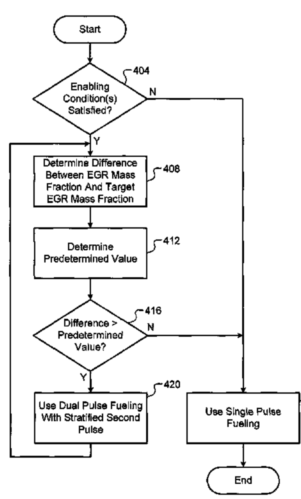
Primary Examiner — Joseph Dallo

(57) **ABSTRACT**

A fuel control system of a vehicle includes an injection control module and a command module. The injection control module determines a first target amount of fuel for a combustion event of an engine. A command module selectively command the injection control module to provide two fuel injections when a torque request decreases. In response to the command, the injection control module: determines second and third target amounts of fuel based on the first target amount; provides a first fuel injection during the combustion event based on the second target amount; and provides a second fuel injection during a compression stroke of the combustion event based on the third target amount.

18 Claims, 7 Drawing Sheets



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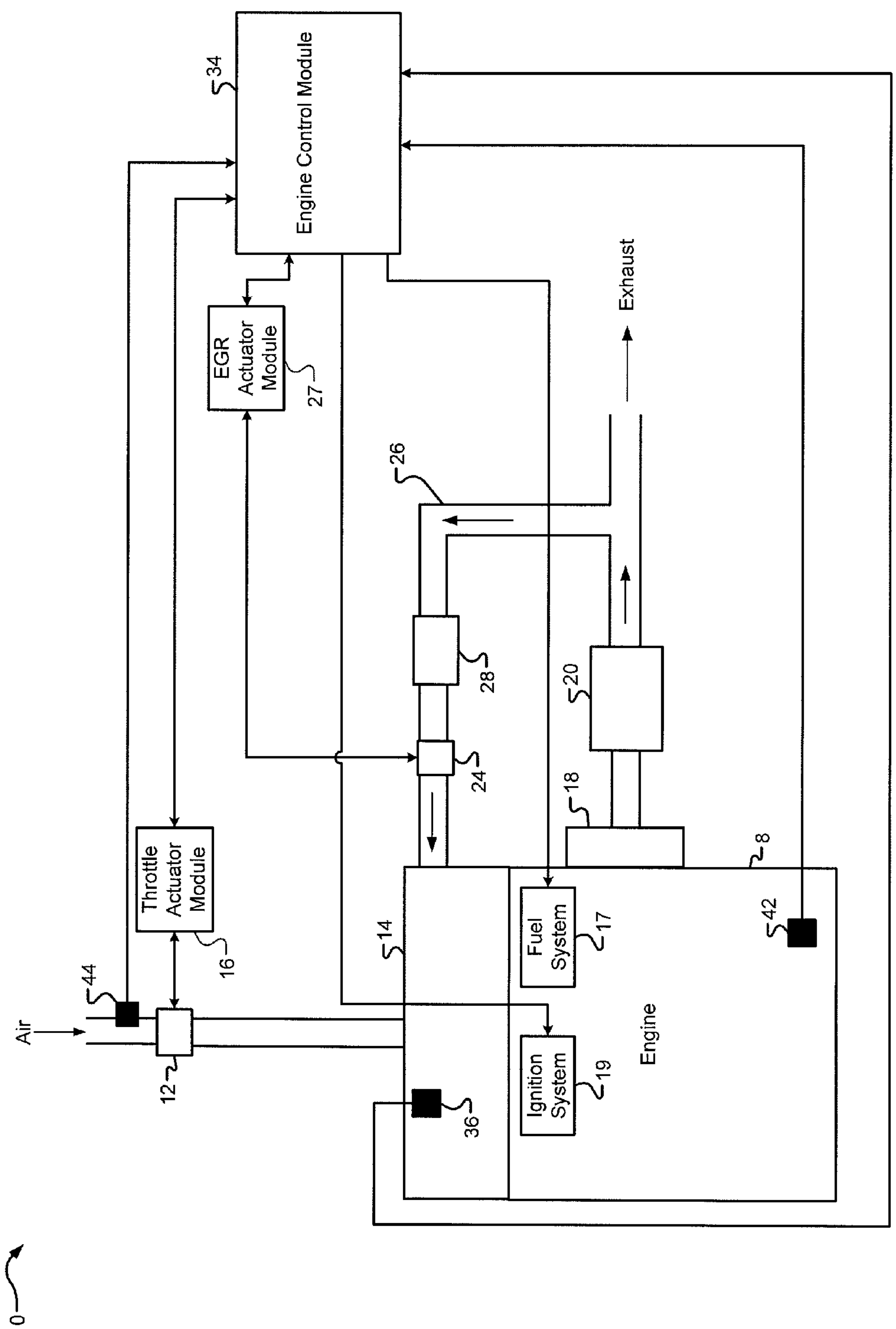
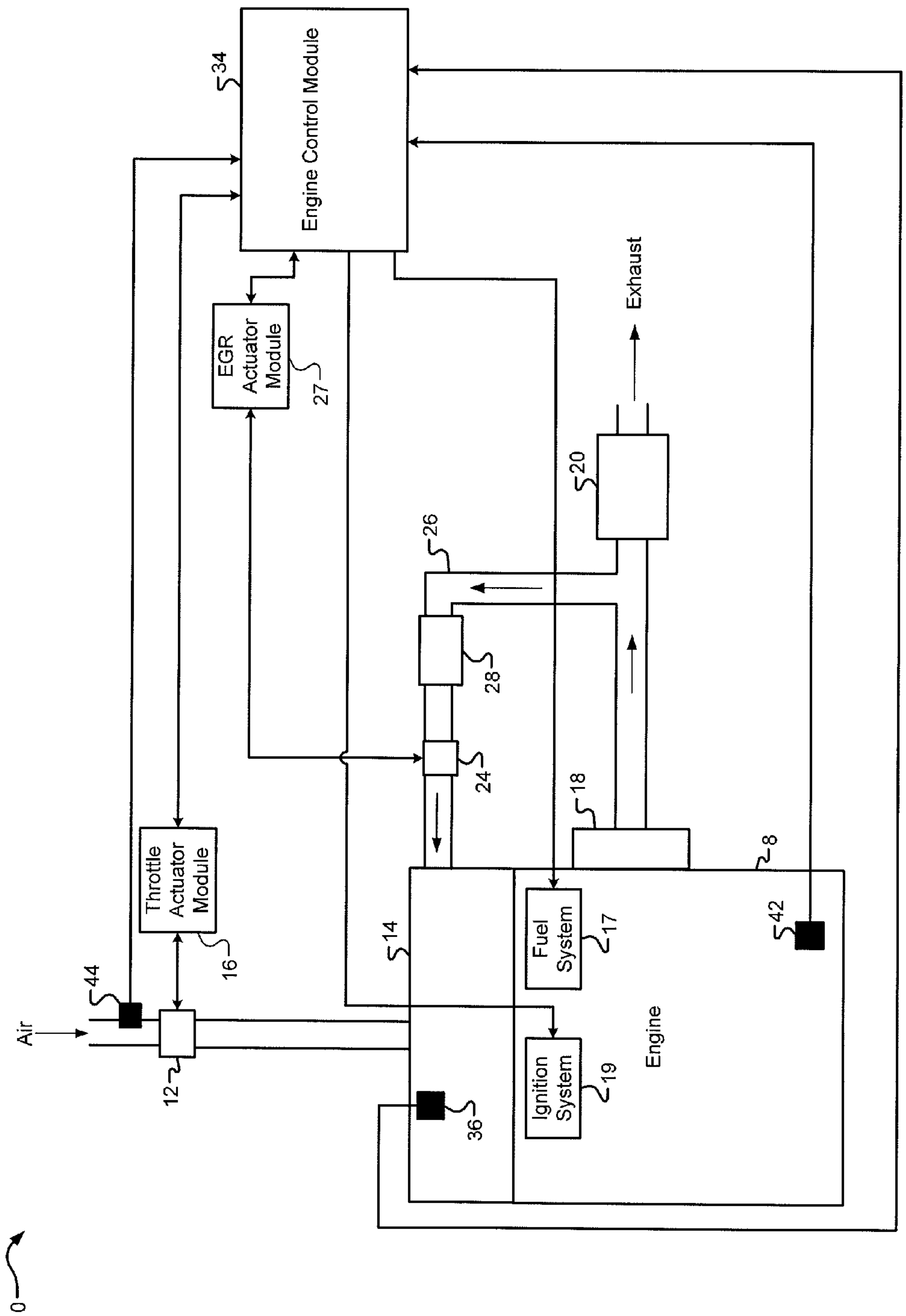

Engine Control Module
34
EGR Actuator Module
27
Exhaust
26
28
20
24
18
8
Throttle Actuator Module
16
44
Air
12
14
Fuel System
17
42
Engine
Ignition System
19
36
10

FIG. 1A


Engine Control Module
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EGR Actuator Module
27
Exhaust
20
26
28
24
18
8
Throttle Actuator Module
16
44
Air
12
14
Fuel System
17
42
Engine
Ignition System
19
36
10

FIG. 1B

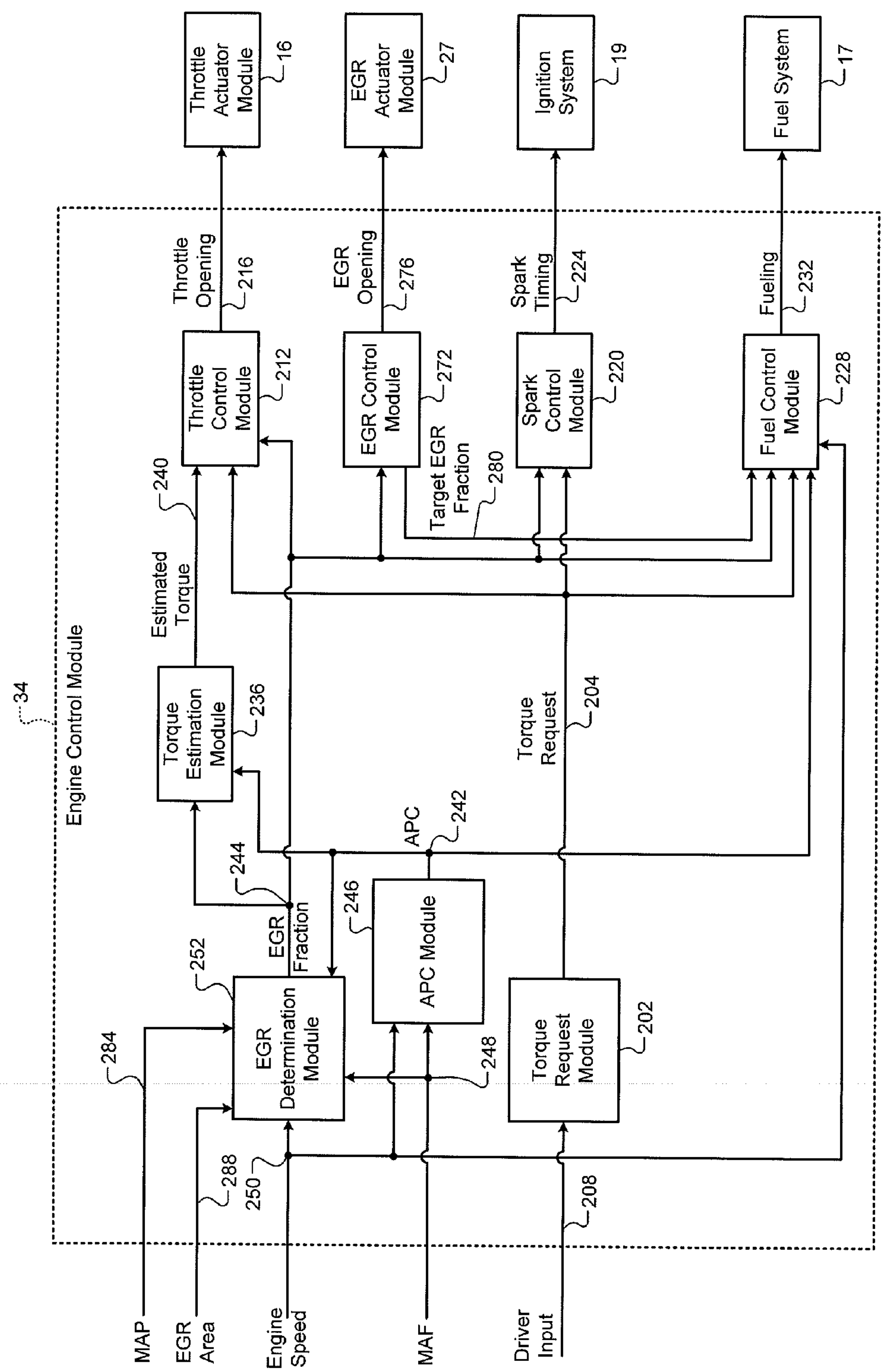
Engine Control Module
34
Throttle Actuator Module
16
EGR Actuator Module
27
Ignition System
19
Fuel System
17
Throttle Opening
216
EGR Opening
276
Spark Timing
224
Fueling
232
Throttle Control Module
212
EGR Control Module
272
Spark Control Module
220
Fuel Control Module
228
Target EGR Fraction
280
240
Estimated Torque
Torque Estimation Module
236
Torque Request
204
APC
242
244
EGR Fraction
246
252
APC Module
EGR Determination Module
Torque Request Module
202
284
248
288
250
208
MAP
EGR Area
Engine Speed
MAF
Driver Input

FIG. 2

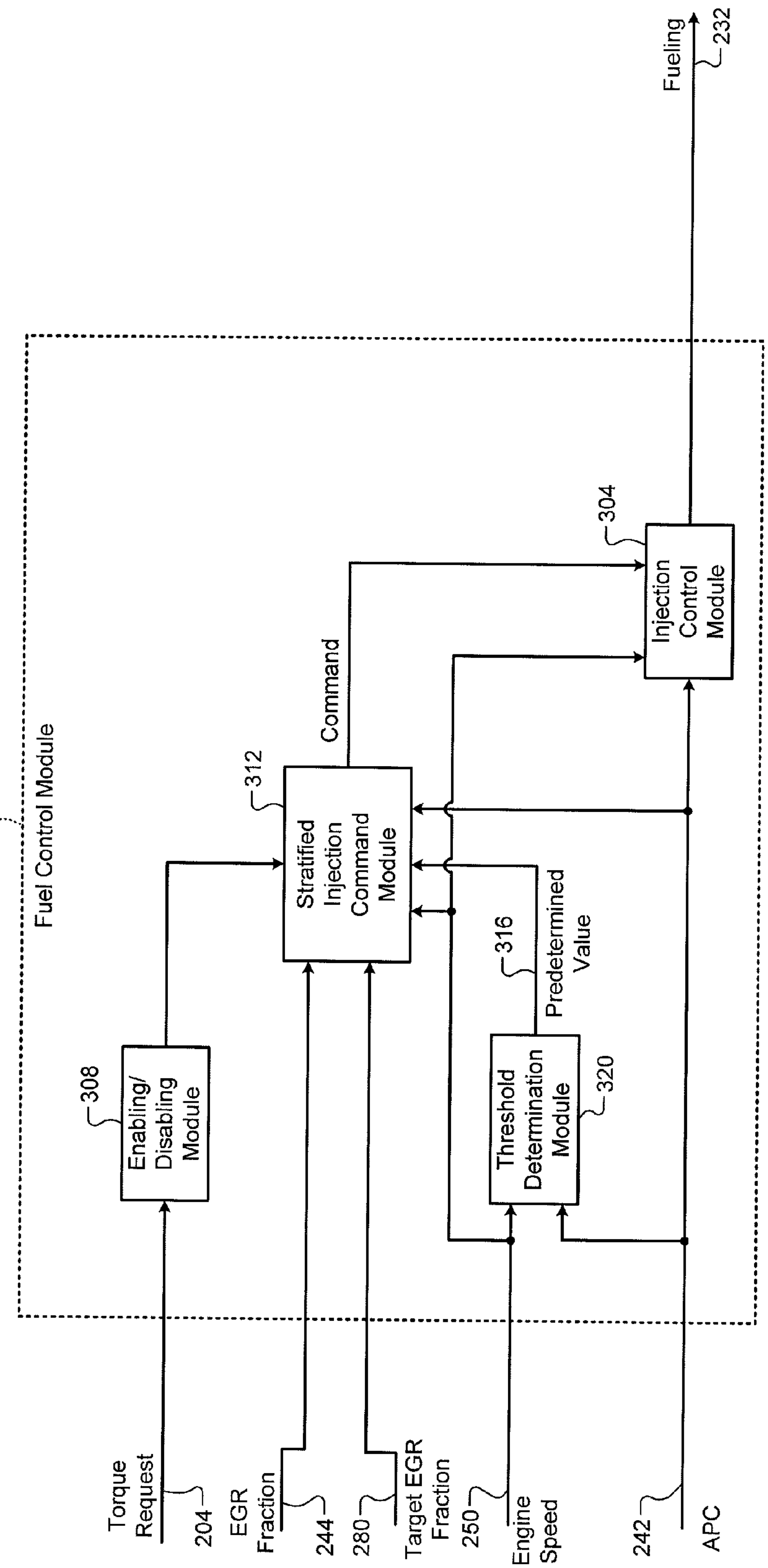
228
Fuel Control Module
Torque Request
204
EGR Fraction
244
280
Target EGR Fraction
250
Engine Speed
242
APC
308
Enabling/ Disabling Module
312
Stratified Injection Command Module
Command
316
Predetermined Value
320
Threshold Determination Module
304
Injection Control Module
Fueling
232

FIG. 3A

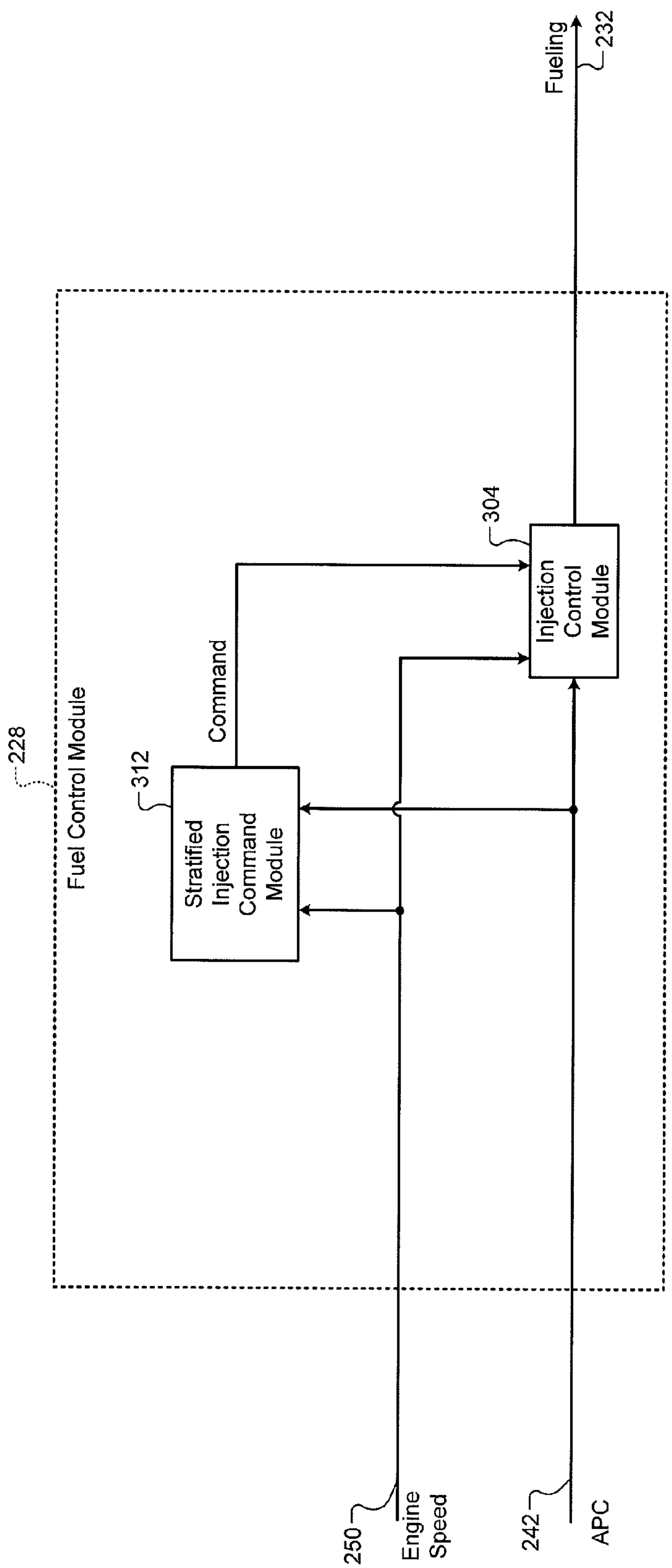
228
Fuel Control Module
312
Stratified Injection Command Module
Command
304
Injection Control Module
Fueling
232
250
Engine Speed
242
APC

FIG. 3B

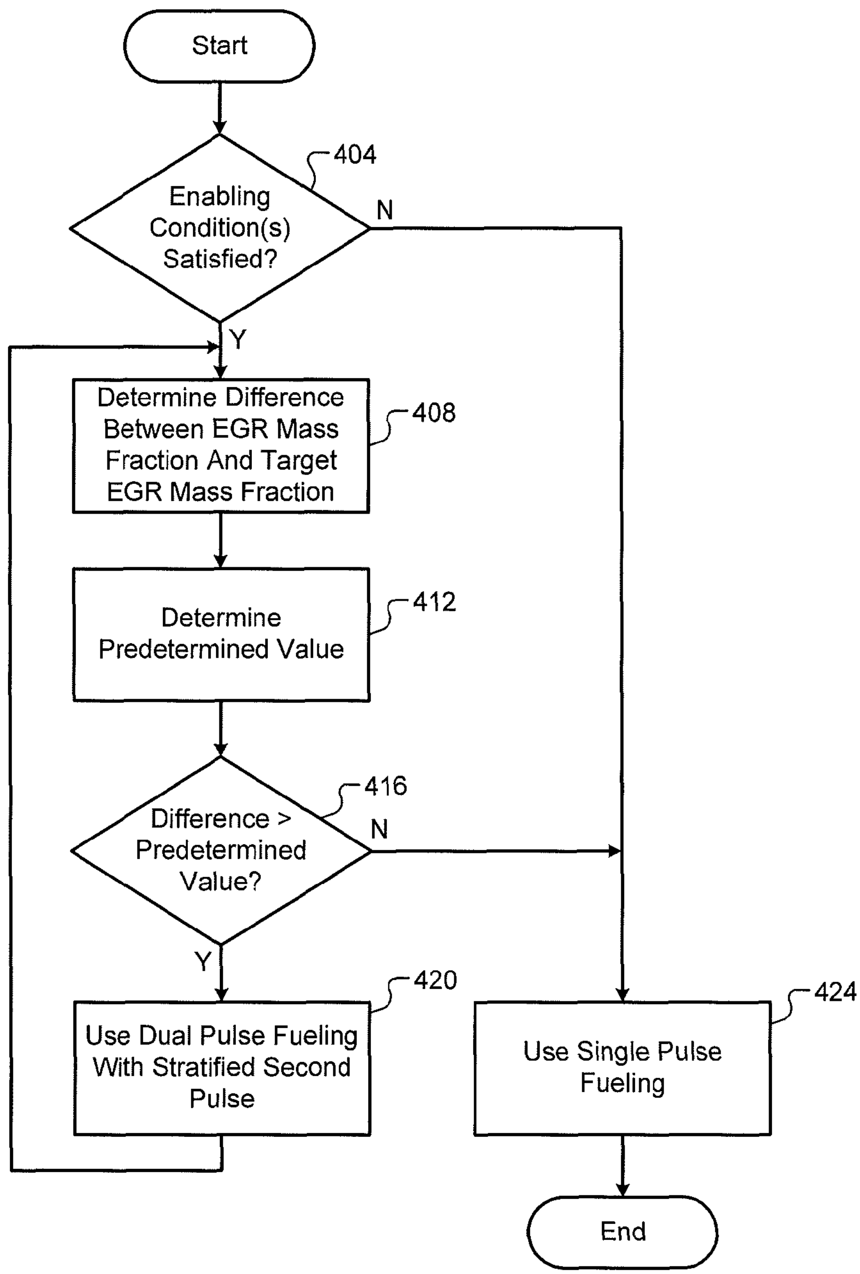
Start
404
Enabling Condition(s) Satisfied?
N
Y
Determine Difference Between EGR Mass Fraction And Target EGR Mass Fraction
408
Determine Predetermined Value
412
416
Difference > Predetermined Value?
N
Y
420
Use Dual Pulse Fueling With Stratified Second Pulse
424
Use Single Pulse Fueling
End

FIG. 4

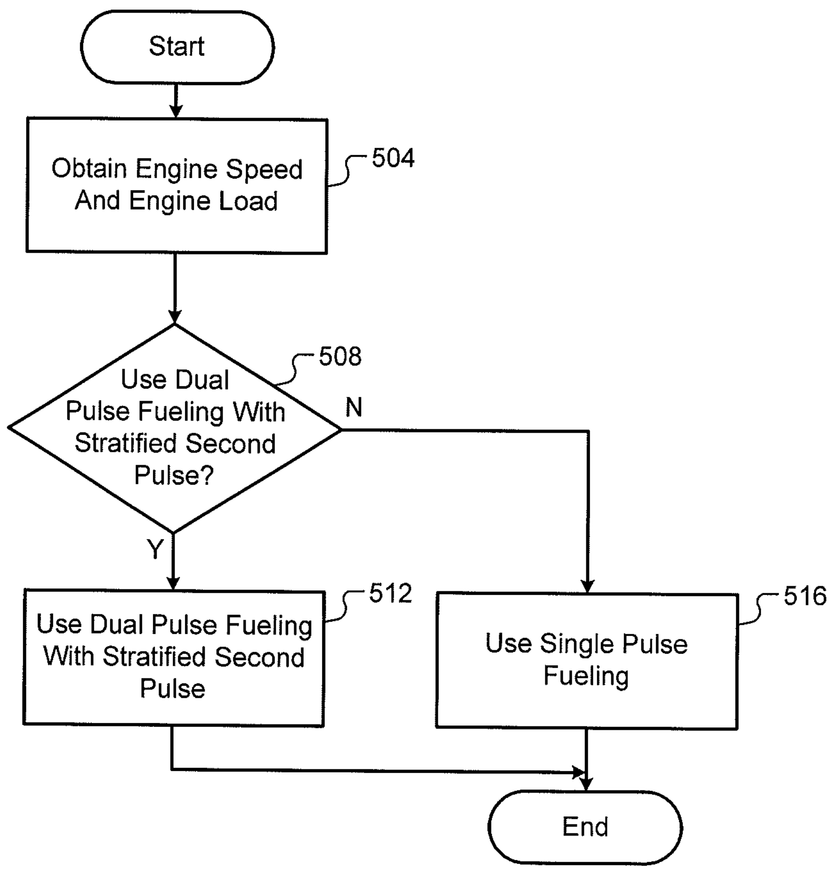
Start
Obtain Engine Speed And Engine Load
504
Use Dual Pulse Fueling With Stratified Second Pulse?
508
N
Y
Use Dual Pulse Fueling With Stratified Second Pulse
512
Use Single Pulse Fueling
516
End

FIG. 5

EXHAUST GAS RECIRCULATION CONTROL SYSTEMS AND METHODS

FIELD

The present disclosure relates to internal combustion engines and more specifically to exhaust gas recirculation control systems and methods.

BACKGROUND

The background description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

An engine combusts air and fuel to generate torque. Air flows into the engine through an intake system. The intake system may include a throttle valve and an intake manifold. Fuel is provided by one or more fuel injectors. The engine outputs torque to a transmission. The transmission transfers torque to one or more wheels. Exhaust resulting from combustion is expelled from the engine to an exhaust system.

An exhaust gas recirculation (EGR) system re-circulates exhaust back to the intake system. For exhaust to flow back to the intake system, pressure within the exhaust system must be greater than a pressure where the exhaust enters the intake system. The EGR system maybe controlled such that a target mixture of exhaust, air, and fuel is provided to each cylinder. The engine may not operate as intended when the target mixture is not maintained.

SUMMARY

A fuel control system of a vehicle includes an injection control module and a command module. The injection control module determines a first target amount of fuel for a combustion event of an engine. A command module selectively command the injection control module to provide two fuel injections when a torque request decreases. In response to the command, the injection control module: determines second and third target amounts of fuel based on the first target amount; provides a first fuel injection during the combustion event based on the second target amount; and provides a second fuel injection during a compression stroke of the combustion event based on the third target amount.

In further features, the fuel control system further includes an enabling/disabling module that disables the command module when a decrease in the torque request is less than a predetermined value.

In yet further features, the fuel control system further includes an enabling/disabling module that disables the command module when a decrease in a target mass fraction of recirculated exhaust gas is less than a predetermined value.

In still further features, the command module determines whether to command the injection control module to provide two fuel injections based on a difference between an estimated mass fraction of recirculated exhaust gas in a gas charge of the combustion event and a target mass fraction of recirculated exhaust gas for the combustion event.

In further features, the command module commands the injection control module to provide two fuel injections when the difference is greater than a predetermined value.

In yet further features, the fuel control system further includes a threshold determination module that determines the predetermined value based on an engine speed.

In still further features, the fuel control system further includes a threshold determination module that determines the predetermined value based on an engine load.

In further features, the injection control module begins and ends the second fuel injection during the compression stroke of the combustion event.

In yet further features, the injection control module determines the second and third target amounts further based on a predetermined percentage.

In still further features, the injection control module determines the predetermined percentage based on at least one of an engine speed and an engine load.

A fuel control method for a vehicle, includes: determining a first target amount of fuel for a combustion event of an engine; and selectively commanding provision of two fuel injections when a torque request decreases. The fuel control method further includes, in response to the command: determining second and third target amounts of fuel based on the first target amount; providing a first fuel injection during the combustion event based on the second target amount; and providing a second fuel injection during a compression stroke of the combustion event based on the third target amount.

In further features, the fuel control method further includes preventing the commanding when a decrease in the torque request is less than a predetermined value.

In still further features, the fuel control method further includes preventing the commanding when a decrease in a target mass fraction of recirculated exhaust gas is less than a predetermined value.

In yet further features, the fuel control method further includes determining whether to command provision of two fuel injections based on a difference between an estimated mass fraction of recirculated exhaust gas in a gas charge of the combustion event and a target mass fraction of recirculated exhaust gas for the combustion event.

In further features, the fuel control method further includes commanding provision of two fuel injections when the difference is greater than a predetermined value.

In still further features, the fuel control method further includes determining the predetermined value based on an engine speed.

In yet further features, the fuel control method further includes determining the predetermined value based on an engine load.

In further features, the fuel control method further includes beginning and ending the second fuel injection during the compression stroke of the combustion event.

In still further features, the fuel control method further includes determining the second and third target amounts further based on a predetermined percentage.

In yet further features, the fuel control method further includes determining the predetermined percentage based on at least one of an engine speed and an engine load.

Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIGS. **1**A and **1**B are functional block diagrams of example engine systems according to the present disclosure;

FIG. **2** is a functional block diagram of an example engine control system according to the present disclosure;

FIGS. **3**A-**3**B are functional block diagrams example fuel control modules according to the present disclosure; and

FIGS. **4**-**5** are flowcharts depicting example methods of controlling fueling according to the present disclosure.

In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

An engine combusts air and fuel within cylinders to produce drive torque for a vehicle. The engine outputs exhaust resulting from combustion to an exhaust system. An exhaust gas recirculation (EGR) system re-circulates exhaust from the exhaust system back to an intake system.

A gas charge is drawn into a cylinder of the engine for each combustion event of the engine. The gas charge may include air drawn through a throttle valve, exhaust recirculated via the EGR system, and one or more other gasses, such as fuel vapor from a vapor purge system.

An engine control module (ECM) generates target mass fractions of air, EGR, and fuel vapor for combustion events and controls actuators based on the targets. Under some circumstances, however, the EGR mass fraction target may decrease and the actual EGR mass fraction may increase. For example only, the ECM may decrease the EGR mass fraction target when the driver releases an accelerator pedal while the vehicle is moving. The actual mass fraction of EGR, however, may increase after the driver releases the accelerator pedal.

When the EGR mass fraction target decreases and the actual mass fraction of EGR may increase, the ECM of the present disclosure splits fueling into two separate injections. The later one of the two fuel injections is performed during the compression stroke of a combustion event to provide a stratified charge. The provision of two separate fuel injections where the later one of the injections is performed during the compression stroke may provide smoother engine operation as compared to operating using a single fuel injection.

Referring now to FIGS. **1**A and **1**B, functional block diagrams of examples of an engine system **10** are presented. While the engine system **10** will be discussed in terms of a spark ignition engine system, the present application is also applicable to other types of engine systems including compression ignition engine systems and hybrid engine systems.

Air is drawn into an engine **8** through an intake system. The intake system may include a throttle valve **12** and an intake manifold **14**. Air may flow into the engine **8** through the throttle valve **12** and the intake manifold **14**. The throttle valve **12** regulates airflow into the intake manifold **14**. A throttle actuator module **16** controls actuation of the throttle valve **12**. The engine **8** combusts an air/fuel mixture within cylinders of the engine **8**. A fuel system **17** selectively injects fuel into the engine **8**. An ignition system **19** selectively provides spark to the engine **8** for combustion.

Combustion of the air/fuel mixture drives a crankshaft and produces exhaust. The engine **8** outputs the exhaust to an exhaust manifold **18**. A catalyst **20** receives the exhaust from the exhaust manifold **18** and reacts with various components of the exhaust. For example only, the catalyst **20** may include a three-way catalyst (TWC), a catalytic converter, or another suitable type of catalyst.

An EGR system selectively recirculates a portion of the exhaust back to the intake system. While recirculation of exhaust back to the intake manifold **14** is shown and will be discussed, exhaust can be recirculated back to other locations in the intake system. The EGR system includes an EGR valve **24** and an EGR conduit **26**. Operation of the engine **8** creates a vacuum (low pressure relative to ambient pressure) within the intake manifold **14**. Opening the EGR valve **24** allows exhaust to be recirculated back to the intake manifold **14**. An EGR actuator module **27** may control actuation of the EGR valve **24**.

The EGR system may also include an EGR cooler **28** that cools exhaust as the exhaust flows through the EGR cooler **28** on its way back to the intake manifold **14**. In various implementations, the EGR system may further include a cooler bypass system that can be controlled to allow exhaust to bypass the EGR cooler **28** on its way back to the intake manifold **14**. The exhaust may be recirculated back to the intake manifold **14** from downstream of the catalyst **20** as shown in FIG. **1**A. As shown in FIG. **1**B, the exhaust may alternatively be recirculated back to the intake manifold **14** from upstream of the catalyst **20**.

While the present disclosure is shown in the context of a naturally aspirated engine, the present disclosure is also applicable to engines with one or more boost devices, such as turbochargers, superchargers, or combinations thereof. Engines with one or more boost devices may include different EGR systems using different locations for where exhaust gas is drawn from (e.g., from an exhaust manifold or downstream of a turbocharger turbine) and/or where exhaust gas is provided to the intake system (e.g., upstream of the intake manifold or upstream of a turbocharger compressor).

An engine control module (ECM) **34** regulates operation of the engine system **10**. For example, the ECM **34** may control opening of the throttle valve **12** via the throttle actuator module **16**, opening of the EGR valve **24** via the EGR actuator module **27**, fuel injection amount and timing via the fuel system **17**, and spark timing via the ignition system **19**. The ECM **34** may also control the operation of the intake and exhaust valve actuators, boost devices, and/or one or more other suitable engine actuators.

The ECM **34** communicates with various sensors, such as a manifold absolute pressure (MAP) sensor **36**, an engine speed sensor **42**, a mass air flow (MAF) sensor **44**, and/or one or more other suitable sensors. The MAP sensor **36** generates a MAP signal indicating an absolute pressure in the intake manifold **14**. The engine speed sensor **42** generates a signal based on rotation of the crankshaft. An engine speed, in revolutions per minute (RPM), can be determined based on the rotation of the crankshaft. The MAF sensor **44** generates a MAF signal indicating mass flowrate of air into the intake manifold **14**.

Referring now to FIG. **2**, a functional block diagram of an example implementation of the ECM **34** is presented. A torque request module **202** may determine a torque request **204** based on one or more driver inputs **208**, such as an accelerator pedal position, a brake pedal position, a cruise control input, and/or one or more other suitable driver inputs. The torque request module **202** may determine the torque request **204** additionally or alternatively based on one or more other torque requests, such as torque requests generated by the ECM **34** and/or torque requests received from other modules of the vehicle, such as a transmission control module, a hybrid control module, a chassis control module, etc. One or more engine actuators may be controlled based on the torque request **204** and/or one or more other vehicle operating parameters.

For example, a throttle control module **212** may determine a target throttle opening **216** based on the torque request **204**. The throttle actuator module **16** may adjust opening of the throttle valve **12** based on the target throttle opening **216**. A spark control module **220** may determine a target spark timing **224** based on the torque request **204**. The ignition system **19** may generate spark based on the target spark timing **224**. A fuel control module **228** may determine one or more target fueling parameters **232** based on the torque request **204**. For example, the target fueling parameters **232** may include number of fuel injection pulses (per combustion event), timing for each pulse, and amount for each pulse. The fuel system **17** may inject fuel based on the target fueling parameters **232**.

A torque estimation module **236** may estimate a torque output of the engine **8**. The estimated torque output of the engine **8** will be referred to as an estimated torque **240**. The throttle control module **212** may selectively adjust the target throttle opening **216** based on the estimated torque **240**. For example, the throttle control module **212** may use the estimated torque **240** to perform closed-loop control of one or more engine air flow parameters, such as throttle area, MAP, and/or one or more other suitable air flow parameters.

The torque estimation module **236** may determine the estimated torque **240** using a torque relationship. For example, the torque estimation module **236** may determine the estimated torque **240** using the relationship:

$$T=f(\mathrm{APC},S,I,E,\mathrm{AF},\mathrm{OT},\#,\mathrm{EGR}),$$

where torque (T) is the estimated torque **240** and is a function of air per cylinder (APC) **242**, spark advance/timing (S), intake opening timing and duration (I), exhaust opening timing and duration (E), air/fuel ratio (AF), oil temperature (OT), number of activated cylinders (#), and EGR mass fraction (EGR) **244**. This relationship may be embodied as an equation and/or as a mapping (e.g., lookup table).

An APC module **246** may determine the APC **242**, for example, based on a MAF **248** and an engine speed **250**. The MAF **248** may be measured using the MAF sensor **44**. The engine speed **250** may be measured using the engine speed sensor **42**. The APC **242** may correspond to a mass of air expected to be trapped within a cylinder for a combustion event.

An EGR determination module **252** determines the EGR mass fraction **244** as discussed further below. The EGR mass fraction **244** may correspond to an expected mass fraction of EGR to the (total) mass of a gas charge of a next combustion event of the engine **8**.

The spark control module **220** may determine the target spark timing **224** using a spark relationship. The spark relationship may be based on the torque relationship above, inverted to solve for target spark timing. For example only, for a given torque request (T_{Req}), the spark control module **220** may determine the target spark timing **224** using the relationship:

$$S_T=f^{-1}(T_{Req},\mathrm{APC},I,E,\mathrm{AF},\mathrm{OT},\#,\mathrm{EGR}).$$

The spark relationship may be embodied as an equation and/or as a lookup table. The air/fuel ratio (AF) may be the actual air/fuel ratio, for example, as reported by the fuel control module **228**.

One or more other engine actuators may additionally or alternatively be controlled based on the EGR mass fraction **244**. For example, an EGR control module **272** may determine a target EGR opening **276** based on the EGR mass fraction **244** and a target EGR mass fraction **280**. The EGR control module **272** may determine the target EGR mass fraction **280**, for example, based on the torque request **204** and/or one or more other suitable parameters. The EGR actuator module **27** may control opening of the EGR valve **24** based on the target EGR opening **276**. The fuel control module **228** selectively adjusts one or more of the target fueling parameters **232** based on the EGR mass fraction **244**, as discussed further below.

The EGR determination module **252** may determine a steady-state (SS) EGR flowrate. The SS EGR flowrate corresponds to a mass flowrate of EGR back to the intake manifold **14** under SS EGR conditions. SS EGR conditions may refer to times when the SS EGR flowrate varies less than a predetermined amount over a predetermined period.

The EGR determination module **252** may determine the SS EGR flowrate using the relationship:

$$\dot{m}_{EGR}=\frac{C_D*A_T*p_O}{\sqrt{R*T_O}}*\left(\frac{p_T}{p_O}\right)^{\frac{1}{\gamma}}*\left\{\frac{2*\gamma}{\gamma-1}*\left[1-\left(\frac{p_T}{p_O}\right)^{\frac{(\gamma-1)}{\gamma}}\right]\right\}^{\frac{1}{2}}$$

where ($\dot{m}_{EGR}$) is the (present) mass flowrate of EGR back to the engine **8** via the EGR system (i.e., the SS EGR flowrate) and is a function of opening area (A_T) of the EGR valve **24**, pressure (p_O) upstream of the EGR valve **24**, a temperature (T_O), pressure (p_r) downstream of the EGR valve **24** (e.g., a pressure within the intake manifold **14**), and various constants (C_D, R, γ). This relationship may be embodied as equation, such as the equation above, or as a mapping (e.g., a lookup table) that relates the above parameters to the SS EGR flowrate. The pressure within the intake manifold **14** may be MAP **284** measured using the MAP sensor **36**. An EGR position sensor may measure a position of the EGR valve **24**, and opening area **288** of the EGR valve **24** may be determined based on the position of the EGR valve **24**.

For each combustion event of the engine **8**, a gas charge is drawn into a cylinder. The gas charge may include: ambient air drawn through the throttle valve **12**; and exhaust gas recirculated back via the EGR system. The gas charge may also include one or more other gasses, such as fuel vapor provided by a fuel vapor purge system (not shown).

The EGR determination module **252** determines a SS EGR fraction for a next combustion event of the engine **8**. The SS EGR fraction corresponds to a mass fraction of EGR under SS EGR conditions to the mass of the gas charge of the next combustion event of the engine **8**. The EGR determination module **252** determines the SS EGR fraction for the next combustion event based on the SS EGR flowrate and the MAF **248**. The EGR determination module **252** may determine the SS EGR fraction for the next combustion event, for example, using the equation:

$$SSFraction=\frac{\dot{m}_{EGR}}{\dot{m}_{EGR}+\dot{m}_{MAF}},$$

where SSFraction is the SS EGR fraction and is a function of the SS EGR flowrate ($\dot{m}_{EGR}$) and the MAF ($\dot{m}_{MAF}$) **248**.

The EGR determination module **252** may include a ring buffer, a first-in first-out (FIFO) buffer, a shift register, etc. Each time the SS EGR fraction is determined, the EGR determination module **252** stores the SS EGR fraction and an oldest stored value of the SS EGR fraction is removed. The EGR determination module **252** includes a predetermined number of the most recently determined values of the SS EGR fraction.

The EGR determination module **252** determines the EGR mass fraction **244** for the next combustion event of the engine **8** based on a plurality of the stored values of the SS EGR fraction. The EGR determination module **252** may determine the EGR mass fraction **244** for the next combustion event based on an average, such as a weighted average, of a plurality of the stored values of the SS EGR fraction. The values of the SS EGR fraction used to determine the EGR mass fraction **244** may be the most recently determined/stored values.

The EGR determination module **252** may determine the EGR mass fraction **244** for the next combustion event, for example, using the equation:

$$EGRFraction = \frac{\left(\sum_{i=0}^{t-d} (t-d-i) * SSFrac_{t-1-i}\right)}{\left(\sum_{i=0}^{t-d} (t-d-i)\right)},$$

where EGRFraction is the EGR mass fraction **244**, t is a number of combustion events between a combustion event of the engine **8** and a later combustion event where the EGR mass fraction **244** will reach SS (and therefore be equal to the SS EGR fraction) after a transient EGR condition occurs, d is a number of combustion events between a combustion event when a command is made that will cause a transient EGR condition and a later combustion event when the EGR mass fraction **244** will begin to change in response to the command, and SSFrac refers to the one of the stored values of the SS EGR fraction for the combustion event t-1-i combustion events ago. t and d are integers, and d is less than t. An EGR transient condition can occur, for example, in response to changes in the opening of the throttle valve **12**, in the opening of the EGR valve **24**, in pressure within the intake manifold **14**, or another suitable event that causes a change in the mass flowrate of exhaust gas recirculation back to the intake manifold **14**.

In various implementations, t and d may be constant values that are calibrated based on physical factors, such as cylinder volume, volume of the intake manifold **14**, and volume of the EGR system through which exhaust gas travels when recirculated. In various implementations, t and/or d may be variable values and may be set by the EGR determination module **252**. The EGR determination module **252** may set t and/or d, for example, using one or more functions or mappings that relate an engine load parameter, such as the APC **242**, and/or the engine speed **250** to t and/or d. The one or more functions or mappings are calibrated based on the physical factors, such as the cylinder volume, the volume of the intake manifold **14**, and the volume of the EGR system.

Under some circumstances, the fuel control module **228** sets the target fueling parameters **232** to provide two separate fuel injections for a combustion event. The later (second) one of the two fuel injections is performed during the compression stroke of the combustion event to provide a stratified charge within the cylinder for the combustion event. The provision of two separate fuel injections where the later one of the injections is performed during the compression stroke may provide smoother operation of the engine **8** as compared to operation using a single fuel injection. The provision of two separate fuel injections where the later one of the injections is performed during the compression stroke may additionally or alternatively decrease brake specific fuel consumption (BSFC).

Referring now to FIG. **3**A, a functional block diagram of an example implementation of the fuel control module **228** is presented. An injection control module **304** sets the target fueling parameters **232** for a combustion event of a cylinder. Generally, the injection control module **304** may set the target fueling parameters **232** for a combustion event such that fuel is provided for the combustion event in a single fuel injection.

The injection control module **304** may determine a target amount of fuel to be injected for the combustion event based on the APC **242** for the combustion event and/or one or more other suitable parameters. For example, the injection control module **304** may set the target amount of fuel based on the APC **242** and a target air/fuel mixture, such as a stoichiometric air/fuel mixture.

An enabling/disabling module **308** selectively enables and disables a stratified injection command module **312**. The enabling/disabling module **308** may enable and disable the stratified injection command module **312**, for example, based on the torque request **204**. For example only, the enabling/disabling module **308** may enable the stratified injection command module **312** when a decrease in the torque request **204** over a predetermined period is greater than a predetermined value. Conversely, the enabling/disabling module **308** may disable the stratified injection command module **312** when a decrease in the torque request **204** over the predetermined period is less than the predetermined value. For example only, the predetermined value may be approximately 10 percent (%) or another suitable value.

Additionally or alternatively, the enabling/disabling module **308** may enable and disable the stratified injection command module **312** based on the target EGR mass fraction **280**. For example only, the enabling/disabling module **308** may enable the stratified injection command module **312** when a decrease in the target EGR mass fraction **280** over a predetermined period is greater than a predetermined value. Conversely, the enabling/disabling module **308** may disable the stratified injection command module **312** when a decrease in the target EGR mass fraction **280** over the predetermined period is less than the predetermined value. For example only, the predetermined value may be approximately 10%, greater than 10%, or another suitable value. While enabling and disabling the stratified injection command module **312** based on the torque request **204** and/or the target EGR mass fraction **280** have been discussed, the enabling/disabling module **308** may enable the stratified injection command module **312** in response to the occurrence of another suitable event where the EGR mass fraction **244** for one or more combustion events is expected to increase to greater than a predetermined value.

When enabled, the stratified injection command module **312** selectively commands the injection control module **304** to provide two separate fuel injections for the combustion event. The stratified injection command module **312** selectively commands the injection control module **304** based on a difference between the EGR mass fraction **244** and the target EGR mass fraction **280**. For example only, the stratified injection command module **312** may command the injection control module **304** to provide two separate fuel injections when the EGR mass fraction **244** minus the target EGR mass fraction **280** is greater than a predetermined value **316**. Conversely, the stratified injection command module **312** may refrain from commanding the injection control module **304** to provide two separate fuel injections when the EGR mass fraction **244** minus the target EGR mass fraction **280** is less than the predetermined value **316**.

A threshold determination module **320** may determine the predetermined value **316** based on the engine speed **250** and/or an engine load parameter, such as the APC **242**. For example only, the threshold determination module **320** may increase the predetermined value **316** as the engine speed **250** increases and vice versa. The threshold determination module **320** may decrease the predetermined value **316** as the APC **242** increases and vice versa. The threshold determination module **320** may determine the predetermined value **316**, for example, using one or more functions and/or mappings that relate the engine speed **250** and the APC **242** to the predetermined value **316**.

In response to the command, the injection control module **304** sets the target fueling parameters **232** for the combustion event to provide two different fuel injections. The two different fuel injections for the combustion event will be referred to as first and second fuel injections.

The injection control module **304** may determine first and second target amounts of fuel for the first and second fuel injections, respectively, based on the target amount. For example only, the injection control module **304** may set the first target amount equal to the target amount multiplied by a predetermined percentage and set the second target amount equal to the target amount multiplied by a value equal to 100% minus the predetermined percentage. The injection control module **304** may determine the predetermined percentage, for example, based on the engine speed **250** and/or an engine load parameter, such as the APC **242**. In various implementations, the predetermined percentage may be a fixed value.

The injection control module **304** also determines first and second starting timings for the first and second fuel injections, respectively. The first and second starting timings may correspond to crankshaft positions to begin the first and second fuel injections, respectively. The injection control module **304** may determine the first and second timings based on the engine speed **250** and/or an engine load parameter, such as the APC **242**. The injection control module **304** sets the second timing such that the second fuel injection begins and ends during the compression stroke of the combustion event. The second fuel injection is performed during the compression stroke of the combustion event to provide a stratified charge.

Referring now to FIG. **3**B, another functional block diagram of an example of the fuel control module **228** is presented. In various implementations, the stratified injection command module **312** may selectively command the injection control module **304** to provide two separate fuel injections for the combustion event based on the engine speed **250** and/or an engine load parameter, such as the APC **242**.

For example only, the stratified injection command module **312** may determine whether or not to command the injection control module **304** to provide two separate fuel injections using a mapping that indicates whether or not to command the injection control module **304** to provide two separate fuel injections based on the engine speed **250** and the engine load parameter, such as the APC **242**. The entries of the mapping may be calibrated such that the stratified injection command module **312** commands the injection control module **304** to provide two separate fuel injections when, under the engine speed and engine load conditions, the use of two separate fuel injections will reduce BSFC and amounts of constituents of the resulting exhaust will be less than respective predetermined values.

Referring now to FIG. **4**, a flowchart depicting an example method of controlling fueling is presented. Control may begin with **404** where the enabling/disabling module **308** determines whether one or more enabling conditions are satisfied. For example, the enabling/disabling module **308** may determine whether a decrease in the torque request **204** over a predetermined period is greater than a predetermined value and/or whether a decrease in the target EGR mass fraction **280** over a predetermined period is greater than a predetermined value. If **404** is true, the enabling/disabling module **308** enables the stratified injection command module **312**, and control continues with **408**. If **404** is false, the enabling/disabling module **308** disables the stratified injection command module **312**, and control may transfer to **424**, which is discussed further below.

At **408**, the stratified injection command module **312** determines the difference between the EGR mass fraction **244** and the target EGR mass fraction **280**. For example, the stratified injection command module **312** may set the difference equal to the EGR mass fraction **244** minus the target EGR mass fraction **280**. At **412**, the threshold determination module **320** determines the predetermined value **316**. The threshold determination module **320** may determine the predetermined value **316**, for example, using one or more functions and/or mappings that relate the engine speed **250** and an engine load parameter, such as the APC **242**, to the predetermined value **316**.

The stratified injection command module **312** determines whether the difference (between the EGR mass fraction **244** and the target EGR mass fraction **280**) is greater than the predetermined value **316**. If **416** is true, the stratified injection command module **312** commands the injection control module **304** to provide two separate fuel injections, and control continues with **420**. If **416** is false, the stratified injection command module **312** does not command the injection control module **304** to provide two separate fuel injections, and control transfers to **424**.

At **420**, the injection control module **304** determines the first and second amounts and the first and second timings for the first and second fuel injections, respectively, for a combustion event. The first and second fuel injections are performed for the combustion event based on the first and second amounts and the first and second timings, respectively. The second fuel injection is performed during the compressions stroke of the combustion event to provide a stratified charge. Control may return to **408** after **420**.

At **424**, the injection control module **304** may set the target fueling parameters for the combustion event to provide fuel in a single fuel injection. Fuel is then injected for the combustion event in a single fuel injection. Control may end after **424**. While control is shown and discussed as ending, control may instead return to **404**.

Referring now to FIG. **5**, a flowchart depicting an example method of controlling fueling is presented. Control may begin with **504** where the stratified injection command module **312** receives the engine speed **250** and an engine load parameter, such as the APC **242**.

At **508**, the stratified injection command module **312** determines whether to command the injection control module **304** to provide two separate fuel injections for a combustion event. The stratified injection command module **312** may selectively command the injection control module **304** to provide two separate fuel injections for the combustion event based on the engine speed **250** and/or the APC **242**. For example only, the stratified injection command module **312** may determine whether or not to command the injection control module **304** to provide two separate fuel injections using a mapping that indicates whether or not to command the injection control module **304** based on the engine speed **250** and the APC **242**. If **508** is true, control continues with **512**. If **512** is false, control continues with **516**.

At **512**, the injection control module **304** determines the first and second amounts and the first and second timings for the first and second fuel injections, respectively, for a combustion event. The first and second fuel injections are performed for the combustion event based on the first and second amounts and the first and second timings, respectively. The second fuel injection is performed during the compressions stroke of the combustion event to provide a stratified charge.

At **516**, the injection control module **304** may set the target fueling parameters for the combustion event to provide fuel in a single fuel injection. Fuel is then injected for the combustion event in a single fuel injection. Control may end after **512** or **516**. While control is shown and discussed as ending, control may instead return to **504**.

The foregoing description is merely illustrative in nature and is in no way intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A or B or C), using a non-exclusive logical OR. It should be understood that one or more steps within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure.

In this application, including the definitions below, the term module may be replaced with the term circuit. The term module may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC); a digital, analog, or mixed analog/digital discrete circuit; a digital, analog, or mixed analog/digital integrated circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor (shared, dedicated, or group) that executes code; memory (shared, dedicated, or group) that stores code executed by a processor; other suitable hardware components that provide the described functionality; or a combination of some or all of the above, such as in a system-on-chip.

The term code, as used above, may include software, firmware, and/or microcode, and may refer to programs, routines, functions, classes, and/or objects. The term shared processor encompasses a single processor that executes some or all code from multiple modules. The term group processor encompasses a processor that, in combination with additional processors, executes some or all code from one or more modules. The term shared memory encompasses a single memory that stores some or all code from multiple modules. The term group memory encompasses a memory that, in combination with additional memories, stores some or all code from one or more modules. The term memory may be a subset of the term computer-readable medium. The term computer-readable medium does not encompass transitory electrical and electromagnetic signals propagating through a medium, and may therefore be considered tangible and non-transitory. Non-limiting examples of a non-transitory tangible computer readable medium include nonvolatile memory, volatile memory, magnetic storage, and optical storage.

The apparatuses and methods described in this application may be partially or fully implemented by one or more computer programs executed by one or more processors. The computer programs include processor-executable instructions that are stored on at least one non-transitory tangible computer readable medium. The computer programs may also include and/or rely on stored data.

What is claimed is:

1. A fuel control system of a vehicle, comprising:

an injection control module that determines a first target amount of fuel for a combustion event of an engine; and

a command module that selectively command the injection control module to provide two fuel injections when a torque request decreases and that determines whether to command the injection control module to provide the two fuel injections based on a difference between an estimated mass fraction of recirculated exhaust gas in a gas charge of the combustion event and a target mass fraction of recirculated exhaust gas for the combustion event,

wherein, in response to the command, the injection control module:

determines second and third target amounts of fuel based on the first target amount;

provides a first one of the two fuel injections during the combustion event based on the second target amount; and

provides a second one of the two fuel injections during a compression stroke of the combustion event based on the third target amount.

2. The fuel control system of claim **1** further comprising an enabling/disabling module that disables the command module when a decrease in the torque request is less than a predetermined value.

3. The fuel control system of claim **1** further comprising an enabling/disabling module that disables the command module when a decrease in the target mass fraction of recirculated exhaust gas is less than a predetermined value.

4. The fuel control system of claim **1** wherein the command module commands the injection control module to provide the two fuel injections when the difference is greater than a predetermined value.

5. The fuel control system of claim **4** further comprising a threshold determination module that determines the predetermined value based on an engine speed.

6. The fuel control system of claim **4** further comprising a threshold determination module that determines the predetermined value based on an engine load.

7. The fuel control system of claim **1** wherein the injection control module begins and ends the second one of the two fuel injections during the compression stroke of the combustion event.

8. The fuel control system of claim **1** wherein the injection control module determines the second and third target amounts further based on a predetermined percentage.

9. The fuel control system of claim **8** wherein the injection control module determines the predetermined percentage based on at least one of an engine speed and an engine load.

10. A fuel control method for a vehicle, comprising:

determining a first target amount of fuel for a combustion event of an engine;

determining whether to command provision of two fuel injections based on a difference between an estimated mass fraction of recirculated exhaust gas in a gas charge of the combustion event and a target mass fraction of recirculated exhaust gas for the combustion event;

selectively commanding provision of the two fuel injections when a torque request decreases; and

in response to the command:

determining second and third target amounts of fuel based on the first target amount;

providing a first one of the two fuel injections during the combustion event based on the second target amount; and

providing a second one of the two fuel injections during a compression stroke of the combustion event based on the third target amount.

11. The fuel control method of claim **10** further comprising preventing the commanding when a decrease in the torque request is less than a predetermined value.

12. The fuel control method of claim **10** further comprising preventing the commanding when a decrease in the target mass fraction of recirculated exhaust gas is less than a predetermined value.

13. The fuel control method of claim **10** further comprising commanding provision of the two fuel injections when the difference is greater than a predetermined value.

14. The fuel control method of claim **13** further comprising determining the predetermined value based on an engine speed.

15. The fuel control method of claim **13** further comprising determining the predetermined value based on an engine load.

16. The fuel control method of claim **10** further comprising beginning and ending the second one of the two fuel injections during the compression stroke of the combustion event.

17. The fuel control method of claim **10** further comprising determining the second and third target amounts further based on a predetermined percentage.

18. The fuel control method of claim **17** further comprising determining the predetermined percentage based on at least one of an engine speed and an engine load.

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